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Acoustics of Bells edited by Thomas D. Rossing **FREE**

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formula. The math review is a very basic refresher of the essential methods. Because a review of graphs is very important for many students, the section could have provided a few more worked examples. I find that nonscience students are somewhat uncertain in their ability to use and analyze graphs.

The revised text is an excellent one to use in a first course in the areas of introductory acoustics, musical acoustics, and the acoustics of speech and hearing. The text is easy to read and reasonably well laid out. Some of the illustrations are a bit small and reproduction of a few photographs resulted in a dark illustration. The overall plan for the development of the topics is from the basic physical principles to applications. The teacher can eliminate some of the discussion of applications without altering the flow of the course. One could easily shorten the time spent on musical acoustics for a group of students in the area of speech and hearing. The extensive use of graphs of acoustic spectral components in the description of the sound produced by musical instruments is a very positive feature of the text. This reflects the incorporation of some of the latest research in music acoustics into the text. The authors have given their research interests special attention in the book. The more complete description should motivate the students to search for similar detailed descriptions of sound sources that represent their interests by consulting the references for further reading at the end of each section. Some sections of the book are brief but include a description of the essential and basic concepts. No section of the book seems to have serious errors or omissions. The authors have removed the small defects of the first edition and achieved a book that is easy to use and useful to the teacher.

The teacher who adopts to text should expect to spend class time working some examples of the mathematical exercises. Many of them are more difficult than the worked examples in the text. In a couple of cases a standard equation has to be used for the solution and the only place it is found is in the problem. The authors use the style of presenting equations where the formula is included in the sentence as a part of the prose. Some students find this hard to use and report difficulty in deciding what is important. This is not a serious problem as it provides the teacher with a ready-made way to introduce and explain certain topics.

The suggested demonstrations and list of audiovisual materials are a definite advantage of this textbook for the teacher. One could also have the materials on hand for students to use in an open laboratory or study room.

I have used the text and find it to be well received by the students. The emphasis on music acoustics results in a textbook also suited to a general audience. With the wealth of other texts as an occasional reading assignment in topics of interest to the majority of the class the emphasis on certain topics by the authors of *Music Speech High Fidelity* is not a serious problem. The authors of this textbook have displayed exceptional faith in their unique approach to the teaching of introductory acoustics by making this revision of the book. In my view it should be given serious examination as the text to be used in acoustics for both science and nonscience oriented students.

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Acoustics of Bells

Thomas D. Rossing, Ed.

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xiii + 411 pp. Price \$67.50.

This book is the nineteenth volume in the Hutchinson Ross Benchmark Papers in Acoustics series. The editor of this volume, Thomas D. Rossing, brings to his task a familiarity with a rather extensive bell literature, an expertise from having conducted original research on bells, and a "love affair with bells." The reviewer is a novice when it comes to bell acoustics and so cannot pass final judgment on papers included in the volume or those not included. However, there seems to be a reasonable balance of papers over a wide range of bell topics. A number of papers in the volume have been translated into English from Dutch or German. The editor's comments introducing the volume and topics within the volume are very helpful. One can only wish that they had been more extensive in some cases.

The book contains research papers which span close to a century from Rayleigh's 1890 paper right up to a 1983 paper. An interesting bit of history unfolds in the first eight or so papers of the book where we see significant changes in the measuring instruments used by various investigators. Helmholtz resonators, tuning forks, stethoscopes, vacuum tube oscillators, and microphones were used at various times in keeping with the changing technology. Two intriguing bell "mysteries"—the strike note and the modal patterns—appear early in the volume and are pretty much resolved midway through the volume.

The terminology used in the description of partial tones and modal patterns of bells is often ambiguous and adds to the bell "mysteries" mentioned above. A first-time reader of the volume may find it worthwhile to refer to Table 1 of the editor's comments on p. 62, Table 2 of the Perrin and Charnley paper on p. 332, and Fig. 3 of the Rossing paper on p. 400 to get some orientation in the classification of modal patterns. One point to keep in mind is the way in which meridian nodes—nodal lines passing up from the bell bow through the crown and down to the bell bow on the opposite side—are counted. Some authors describe the lowest mode—designated the hum mode—as having two meridian nodes and no circular nodes (2,0) and others describe it as having four meridian nodes (4,0). Both represent the same vibrational pattern; the (2,0) description counts a nodal line as going from bow to crown to bow; and the (4,0) description counts a nodal line as going from bow to crown. As an aid to the reader the accompanying Table I has been prepared by summarizing some of the descriptive features from several articles in the volume. Eight vibrational mode designations of a tuned bell are shown in Table I along with their modal classifications, their relative frequencies, and their relative strengths.

The book is divided into eight parts with brief author citation and subject indices at the end. Part I: Early investigations consist of four papers which introduce the two primary questions of the vibrational modes and the pitch of the strike note. These papers largely anticipate the "final" results given in later parts of the book: (1) The pitch of the strike note of a bell corresponds to a frequency an octave below the fifth partial (octave mode in Table I). (2) The modal shapes of the first five modes correspond to the patterns (4,0), (4,1), (6,1), (6,1#), (8,1). The function of the proper tuning of the partials is also raised.

Part II: Modes of vibration and tonal characteristics consists of five papers which deal with modal patterns, modal frequencies, decay mechanisms, and mode classification schemes. Efforts were made to systematize the nodal characteristics in terms of meridian and circular nodes. Measurements of partial frequencies and vibration patterns are reported for church bells and carillon bells. Investigations of decay times of partials and the effects on the bell sound of clapper mass, material, shape, and striking point also are reported. Part II closes with a very modern paper (1983) which relates measured frequencies and nodal patterns of a single bell with corresponding frequencies and patterns obtained from finite-element calculations. This paper provides a physical basis for the partial classification scheme and provides a number of insights into bell design.

Part III: Tuning of bells consists of five papers. Bells to be used in a carillon have their first five modes tuned as shown in Table I, with the tuning often being quite precise in relation to the relative frequencies shown. Sometimes higher modes are tuned. "Church bells" follow the same general pattern but their tuning is often less precise. Results of extensive measurements of partial frequencies of over 100 bells are presented. Consideration is given to where material should be removed from a bell via the lathing process used by most foundries to finish the tuning of a cast bell. The final paper in Part III on contemporary Dutch bell-founding might profitably be read as an introduction to the entire book. It contains sections on historical orientation, frequency measurements, bell tuning, partial groups, and musical consequences.

Part IV: Search for the strike note consists of six papers on the origin of the strike note in bells, which is taken by most of the authors to be the same as the pitch of the bell. The strike note is considered as not having physical existence in the partials of the bell tone, but rather to derive from difference tones or residue. Its frequency seems to lie about an octave below that of the fifth mode and it depends on the presence of the fifth mode for its existence. The final two papers in Part IV provide what is currently taken to be the definitive answer to the strike tone mystery. Accordingly, the origin of the strike tone lies in the phenomenon of residue pitch wherein a number of higher-frequency, harmonically related partials give rise to a pitch corresponding to a fundamental frequency not physically present. In this explanation the fifth, seventh, and eighth modes (see Table I), all of which are relatively strong, are in the frequency ratios 4:6:8. The residue phenomenon with these ratios gives rise to a pitch associated with the missing value of 2 which lies an octave below the fifth mode. This pitch also corresponds

TABLE I. Bell modes for a tuned bell with their classifications, relative frequencies, and relative strengths. (Modes numbered 1–5 are the first five modes of a tuned bell; modes numbered 6–8 are not the next sequential modes of a tuned bell but are of importance in describing the strike note. Classification is in terms of the number of bow-to-crown meridian nodes and the number of circular nodes. # designates a circular node in the bow very close to the rim.)

Mode number	Mode name	Classification	Relative frequency	Relative strength
1	Hum	4,0	1.0	strong
2	Prime (fundamental)	4,1	2.0	strong
3	Minor third	6,1	2.4	strong
4	Fifth	6,1 #	3.0	weak
5	Octave (nominal)	8,1	4.0	strong
6	Tenth	8,1 #	5.0	weak
7	Twelfth	10,1	6.0	strong
8	Upper octave	12,1	8.0	strong

closely to the frequency of the second mode.

The explanation given for the origin of the strike note seems plausible and well demonstrated. However, the reviewer is left unsettled regarding the relationship of the strike note to the pitch of the bell. His colleague I. G. Bassett has made measurements of the first five modal frequencies of carillon bells and found them to be quite accurately tuned to the relative frequencies shown in Table I. The frequency ratios for partials one, two, four, and five are 1:2:3:4 which one might expect to give rise to a pitch corresponding to a relative frequency of 1 via the residue phenomenon. Interestingly, the pitch given by the founder for each bell corresponds to the frequency of the first mode of the bell. Does this suggest that the pitch of a bell and its strike note differ by about an octave?

Part V: Bell material, tonal balance, and warble consists of six papers. The first paper reports that bell dimensions and mass influence the bell sound more than considerable changes in composition of the bronze alloy. The next four papers consider the question of tonal balance as related to dimensional scaling (diameter, height, and thickness) with frequency. Tonal effects of clapper weight and travel distance are also considered. The final paper used group theory to classify vibration modes into families on the basis of symmetry operations on the “uniform” bell. Warble in bells is related to the symmetries of slightly nonuniform bells and a method for removing warble is suggested.

Part VI: Chimes and tubular bells consists of two papers. The first paper describes how tubular bells give rise to a bell-like strike tone via the residue effect arising from the frequency ratios 2:3:4 of their modes four,

five, and six. The second paper reported measured and calculated frequencies and modal patterns of tubular bells. Comparison of church bell spectra with those of “pipe-bells” and “piano-bell” chords is given.

Part VII: Electronic carillons consists of two papers that consider the question of bell substitutes to provide bell-like tones without the high cost of cast bells. The first paper deals with electronically amplified bells. The second paper describes the design of rectangular rod vibrators with two pickups to provide more realistic bell sound.

Part VIII: Handbells consists of three papers, the first of which traces out the early history of handbells. The vibrational and tonal characteristics of handbells are described in the other two papers. Of particular interest is the fact that usually only two partials are tuned in a handbell, with the strike tone determined by the lower one. Some nice time-average holographic interferograms of normal modes in a handbell are included.

The reviewer found the *Acoustics of Bells* to be interesting and exciting. Anyone with even a passing interest in bells will find useful information in the book. There is a wealth of information, much of it quite detailed, for anyone more intimately concerned with bells. Whether one chooses to add it to a personal library is largely a question of economics versus interest in bells.

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